Technology Information Update...The Latest from the Labs

Sandia

National Laboratories

Laser Beam Welding Research

Laser Beam Welding (LBW) is a manufacturing process that continues to expand into new industries and applications because of its advantages in achieving deep weld penetration and in minimizing heat input. The trend to automate fusion welding processes has also led to expanded use of lasers as computers are installed to improve product quality through more precise control of the manufacturing process. LBW is ideally suited for automation since the beam can be precisely positioned with optical elements that are located remote from the fusion zone. In addition, fiber optics are now capable of transmitting kilowatts of laser power and are used to carry the laser beam to the end of robotic welding arms.

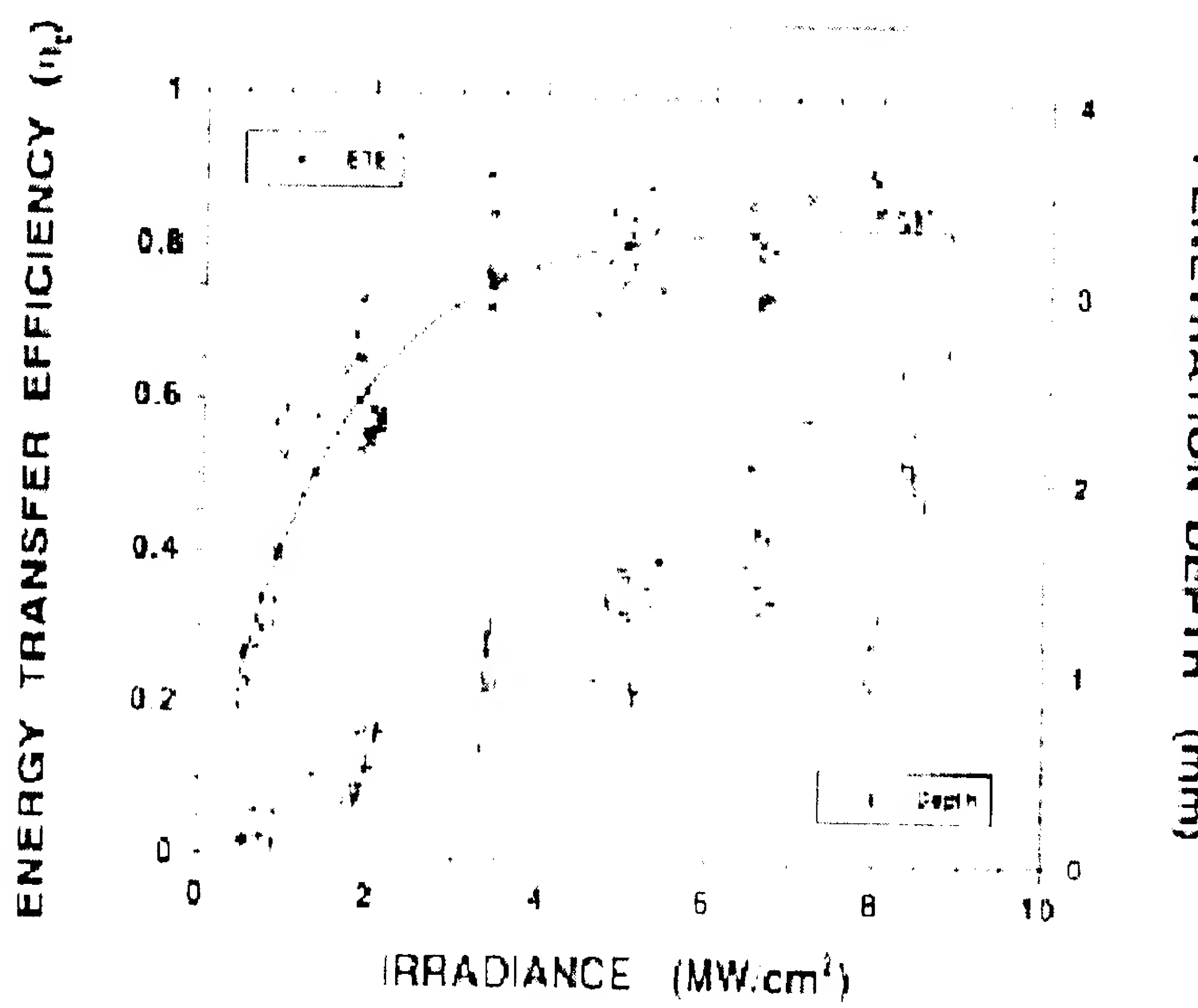
Significant Difference

LBW differs most significantly from traditional electric arc welding processes in the mode of energy transfer. Unlike electric arc energy transfer, laser energy absorption by a material is strongly affected by many factors including the type of laser, the incident power density, and the base metal's reflectivity and surface condition. Two important ``figures of merit" to help characterize laser welding are the energy transfer efficiency and the melting efficiency. Energy transfer efficiency is the ratio of the heat absorbed by the workpiece to the incident laser energy. Melting efficiency is the ratio of the heat necessary to just melt the fusion zone to the heat absorbed by the workpiece. Energy transfer efficiency indicates how much of the laser energy is absorbed by the part, melting efficiency indicates how effectively that absorbed energy is used to produce melting. Both efficiencies are extremely important in manufacturing, and both efficiencies require an accurate determination of the heat input to the part to be made. Since measurements of the heat input to the workpiece are difficult, there has been widespread confusion and lack of agreement in the welding community as to the magnitude of these two efficiencies. This lack of understanding among laser users has led to unsubstantiated claims about the high melting efficiency of the LBW process. Lasers are often believed to be superior to other welding processes and to have performance characteristics that are exceptional.

Superior Levels of Quality

At Sandia, the LBW process has been modeled and studied extensively in recent years because of its importance in the joining of high value precision components that require superior levels of quality. Knowing the heat input has been particularly important at Sandia because welding applications in the DOE weapons complex require the selection of welding processes to minimize heat input to the workpiece and to reduce distortion and thermal damage to heat sensitive components. To understand the LBW process and to help quantify these efficiencies, we have made extensive measurements of the net heat input to the workpiece through the use of a Seebeck envelope calorimeter.

We have found that the energy transfer efficiency for LBW can vary over a range of 20% to 90%, depending primarily on the incident laser beam irradiance. These results as shown in Fig. 1 also indicate that the energy transfer efficiency reaches a high and approximately constant value at an incident beam irradiance of about 4.0 MW/cm^2. The figure also shows that the depth of weld penetration can be varied while still maintaining high levels of energy transfer efficiency.



New Insights

For manufacturing engineers these results provide new insights into the laser welding process. During weld schedule development a knowledge of the energy transfer efficiency can be used to optimize the process and assure weld quality. For example, in laser welding one can select a range of process parameters that will make energy transfer efficiency invariant and thereby assure that uncontrolled changes in the laser spot size do not result in either an increase or decrease in the absorbed power. It is not uncommon for welding engineers to develop weld

schedules where the incident laser beam is defocused. This situation leads to a high fraction of the laser beam power being reflected. In a pulsed Nd:YAG laser welding application at one of our laser welding vendors, the negative consequences of defocusing were dramatically demonstrated when a change in the production fixture tooling led to unapparent but catastrophic drilling of many expensive components. Clearly if one can operate in the plateau region of Fig. 1 a more robust welding process can be assured.

Minimizing Heat Input We have also learned a great deal about the laser's ability to minimize heat input during welding. We have found that the weld process variables and the weld joint geometry can dramatically affect the melting efficiency and that all fusion welding processes can be optimized to produce the same maximum melting efficiency. The laser really possesses no intrinsic advantage for high melting efficiency. It is apparent from our research that the primary advantage of the LBW process in minimizing heat input to the part is due to its ability to make very small or especially deep welds that cannot be made with other welding processes.

Prediction Methodology

To simplify the analysis of laser welding, we have employed dimensionless parameters to diagrammatically present our experimental data that have resulted in equations that can be readily used to estimate the efficiencies of the LBW process. This simple prediction methodology is notable because it requires only a knowledge of the weld schedule and the material properties in order to estimate melting efficiency. The straightforward mathematical relationship between these parameters can be used to quickly estimate the heat input to the part based on the size of the weld or for other optimization tasks such as selecting levels of travel speed and heat source power that will reduce thermal damage to the weldment. For the applications engineer to decide on the cost effectiveness of the LBW process, the model can be used to examine important processing details and to determine the ultimate capabilities of a specific laser before the laser is purchased. To determine the required functional characteristics of the laser for an application, one must consider the production feed rates to be obtained, the size of the fusion zone to be melted, the thermal properties of the materials, and the process efficiencies. All of this information can be obtained from the dimensionless parameter model.

New Studies Planned

At Sandia we are continuing this work and are at present planning to do new calorimetric studies on additional materials with other lasers. This research into laser materials processing also includes accurate measurements of the laser beam spot size to provide needed understanding of its propagation through focusing optics. Laser welding is clearly the welding process of the future but its application can often be limited by a lack of knowledge of the process. We anticipate this increase in the application of LBW and so we seek to extend our understanding of the process.

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